Universitat Politècnica de Catalunya
Facultat de Nàutica de Barcelona

Design of modules for a star-triangle starter based on intensity

Final Degree Project

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ETN
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Index:

1. INTRODUCTION

Nowadays society is more conscious about the reduction of energetic consumption. In this project we will study an alternative method of starting electrical engines, with a PLC (Programmable logic controller), a comparison with the most used one (Start-Delta Starters and by timers). In order to study both it will be necessary to assemble two modules which after the project could be used by students to enforce their electrical practices.

As we now, when we start an electrical engine the value of the current can be between 2 and 7 times the nominal so being quite wary is never a mistake. The timer method is based on a selector that when the time is reached it changes its position from star to triangle, it is simple but when there is a problem and the current isn't low enough the selector will change the position anyway. With the PLC method we want to fix this problem by analysing the current all the time and when it is low enough it sends the signal that makes the selector change its position. Also the PLC can offer a wide range of options.

Another point in favour of using a PLC is that it doesn't have a minimum time working on star, if in 3 seconds the current is sufficiently low the switch will connect the triangle, but the timer has to be programmed, if it is for 5 seconds it will be delayed 2 seconds compared on the PLC which will start the engine faster and that means less consumption because we will finish our work earlier. Maybe 2 seconds doesn't seem a lot but if we count every electrical engine of a ship and add 2 seconds of working every time it is started, we will realize that the reduction is not little.

2. OBJECTIVES

- Explain why and how affects the starting of an engine to the equipment connected.
- Assemble a module for the PLC study and explain all the elements.
- Learn how to design a program for a PLC (Language used: Logic gates, Ladder…).
- Design a module for testing programs of general purpose and create real practices of programming for students.
- Design a module for testing programs of 3 phases, available for start-delta starter.
- Create practices that use the modules assembled that will help students testing their programs.

3. CONCEPTS DESCRIPTION

3.1. PLC (Programmable Logic Controller):

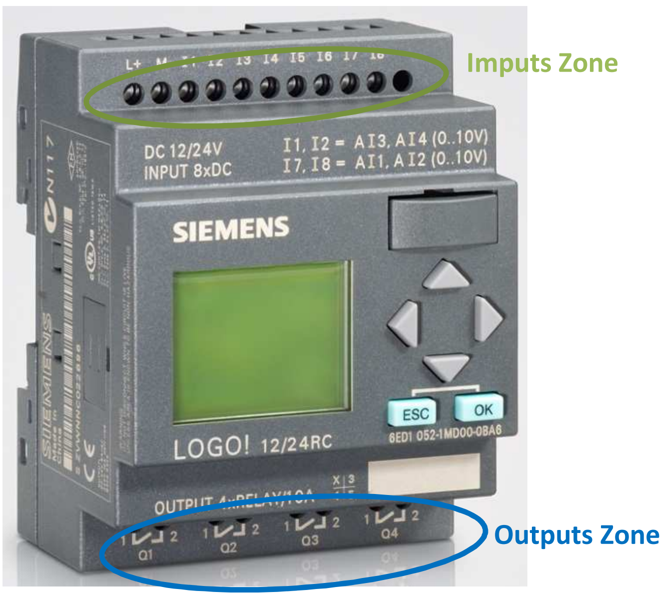
A programmable logic controller (PLC) or programmable controller is a digital computer used for automation of industrial processes, such as control of machinery on factory assembly lines.

Unlike general-purpose computers, the PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. A PLC is an example of a real time system since output results must be produced in response to input conditions within a bounded time, otherwise unintended operation will result.

Also inputs and outputs of a PLC work with digital signals, everything or nothing (1 and 0), so that, in order to control processes that are related to physical parameters (temperature, pressure, humidity…) sensors are used. This sensor transforms analogic functions to digital signal that can be processed by the CPU of the PLC.

It is true that inputs use digital signals but in many cases it is possible to find some inputs that recognise analogic signals.

The PLC's that we are going to work are:



Hence, a programmable logic controller is a specialized computer used to control machines and processes. It therefore shares common terms with typical PC's like central processing unit, memory, software and communications. Unlike a personal computer though the PLC is designed to survive in a rugged industrial atmosphere and to be very flexible in how it interfaces with inputs and outputs to the real world.

The components that make a PLC work can be divided into three core areas.

- The power supply and rack
- The central processing unit (CPU)
- The input/output (I/O) section

PLCs come in many shapes, sizes and also characteristics. They can be so small as to fit in your shirt pocket while more involved controls systems require large PLC racks.

3.1.1. PLC for the three phase module:

- 1 PLC:

Installation type/mounting	
Mounting	on 35 mm DIN rail, 4 spacing units wide
Supply voltage	
115 V DC	Yes
230 V DC	Yes
permissible range, lower limit (DC)	100 V
permissible range, upper limit (DC)	253 V
115 V AC	Yes
230 V AC	Yes
Time of day	
Time switching clocks	
Number	8
Power reserve	80 h
Digital inputs	
Number of digital inputs	8
Digital outputs	
Number of digital outputs	4; Relays
Short-circuit protection	No; external fusing necessary
Relay outputs	
Switching capacity of contacts	
— with inductive load, max.	3 A

— with resistive load, max.	10 A
EMC	
Emission of radio interference acc. to EN 55 011	
Emission of radio interference acc. to EN 55 011 (limit class B)	Yes
Degree and class of protection	
IP20	Yes
Standards, approvals, certificates	
CSA approval	Yes
UL approval	Yes
FM approval	Yes
developed in accordance with IEC 61131	Yes
acc. to VDE 0631	Yes
Marine approval	
Marine approval	Yes
Ambient conditions	
Operating temperature	
min.	0 °C
max.	55 °C
Dimensions	
Width	72 mm
Height	90 mm
Depth	55 mm
last modified:	21/08/14

- 3 Contactors:

Weights	
Weight, approx.	160 g

3.1.2. PLC for the Checking module:

- 1 Transformer:

Technical specifications	
Product	LOGO!Power
Power supply, type	24 V/2.5 Av
Input	
Input	1-phase AC or DC
Supply voltage / at AC / nominal value min.	100 V
Supply voltage / at AC / nominal value max	240 V
Supply voltage	
at AC	85…264 V
Input voltage / at DC	110…300 V
Wide-range input	Yes
Overvoltage resistance	2.3 × Vin rated, 1.3 ms
Mains buffering at Iout rated, min.	40 ms
Mains buffering	at Vin = 187 V
Rated line frequency	50/60 Hz
Rated line range	47...63 Hz
Input current / at nominal level of the input voltage 120 V	1.22 A
Input current / at nominal level of the input voltage 230 V	0.66 A
Switch-on current limiting (+25 °C), max.	46 A
I²t, max.	3 A²·s
Built-in incoming fuse	internal
Output	
Output	Controlled, isolated DC voltage
ated voltage Vout DC	24 V
Total tolerance, static ±	3 %
Static mains compensation, approx.	0.1 %
Static load balancing, approx.	1.5 %
Residual ripple peak-peak, max.	200 mV
Residual ripple peak-peak, typ	10 mV
Spikes peak-peak, max. (bandwidth: 20 MHz)	300 mV
Spikes peak-peak, typ. (bandwidth: 20 MHz)	50 mV
Adjustment range	22.2…26.4 V

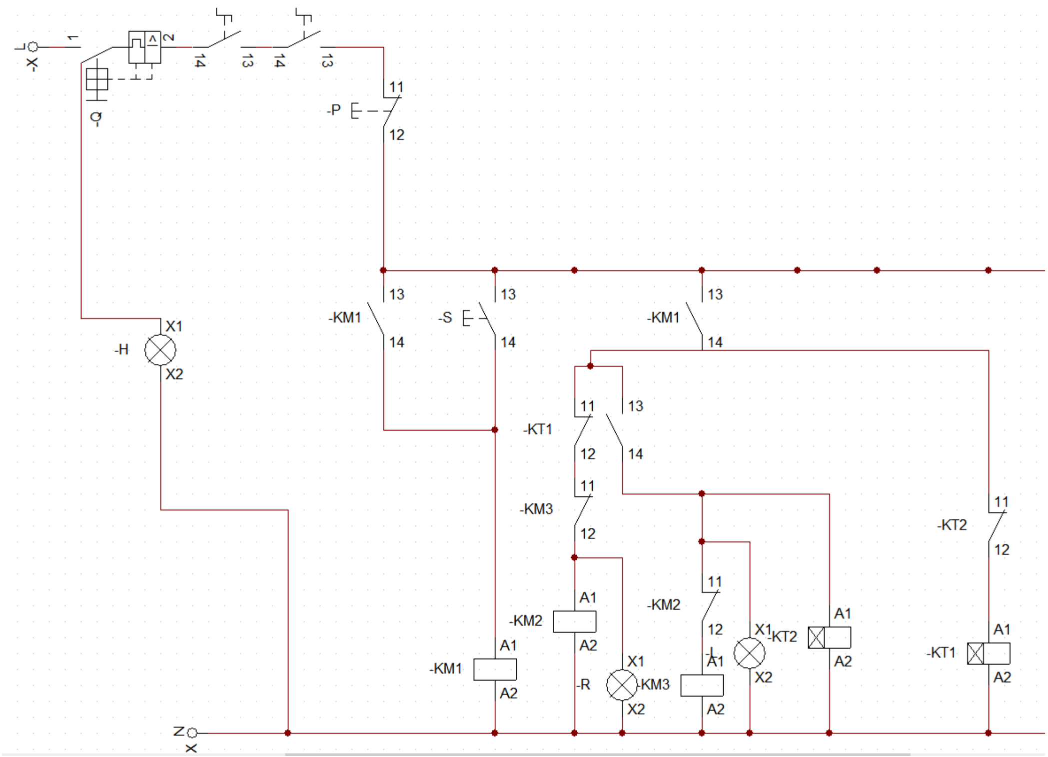
- 1 PLC:

Installation type/mounting	
Mounting	on 35 mm DIN rail, 4 spacing units wide
Supply voltage	
12 V DC	Yes
24 V DC	Yes
permissible range, lower limit (DC)	10.8 V
permissible range, upper limit (DC)	28.8 V
Time of day	
Time switching clocks	
Number	8
Power reserve	80 h
Digital inputs	
Number of digital inputs	8; Of which 4 can be used in analog mode (0 to 10 V)
Digital outputs	
Number of digital outputs	4; Relays
Short-circuit protection	No;
Relay outputs	
Switching capacity of contacts	
— with inductive load, max.	3 A
— with resistive load, max.	10 A
Degree and class of protection	
IP20	Yes
FM approval	Yes
developed in accordance with IEC 61131	Yes
acc. to VDE 0631	Yes
Marine approval	Yes
Ambient conditions	
Operating temperature	
min.	0 °C
max.	55 °C
Dimensions	
Width	72 mm
Height	90 mm
Depth	55 mm

3.2.Power circuit and Command circuit:

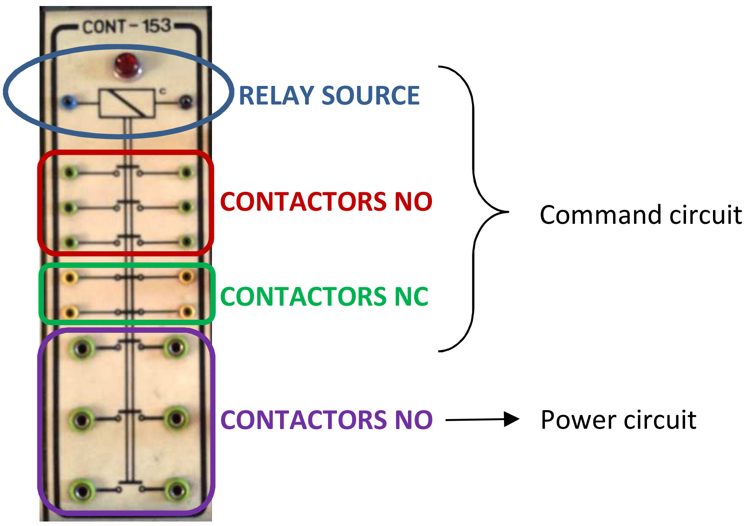
3.2.1. Command circuit:

Command circuit is the CPU of the PLC including inputs and outputs. The user can create a program and download into the PLC which analysing that inputs activate or not the contactors.



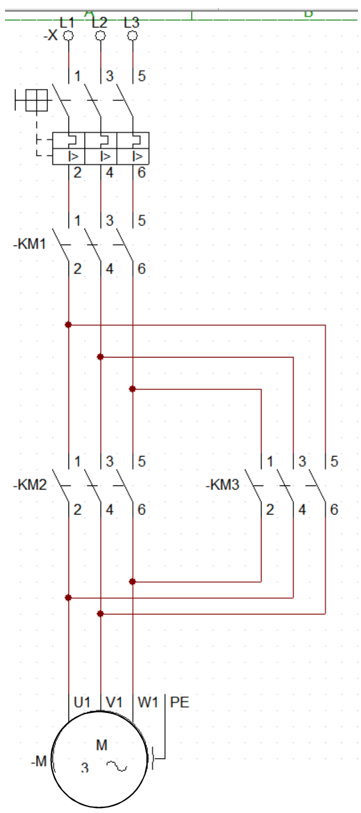
Inputs can be constants, switches etc.. at the below diagram we can observe a command circuit based on switches which depending on the opened and closed there are different relays working. These relays are the ones that communicate with the Power circuit opening or closing it.

The modules of the project will not work which switches, it is necessary to make the control program in the computer and then download it into the PLC, we will only use switches for Start and Stos.



Picture 1: Relay with contactors

3.2.2. Power circuit:

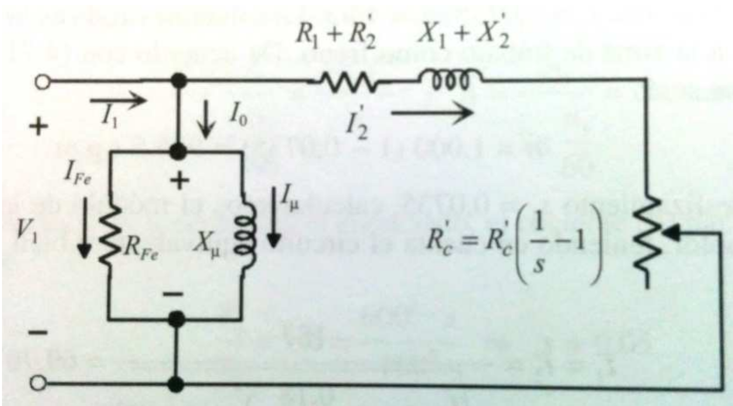


The Power circuit is the one that supplies current to the equipment when the command circuits allows it by opening or closing the switches of the power circuit that completely depend on the relays.

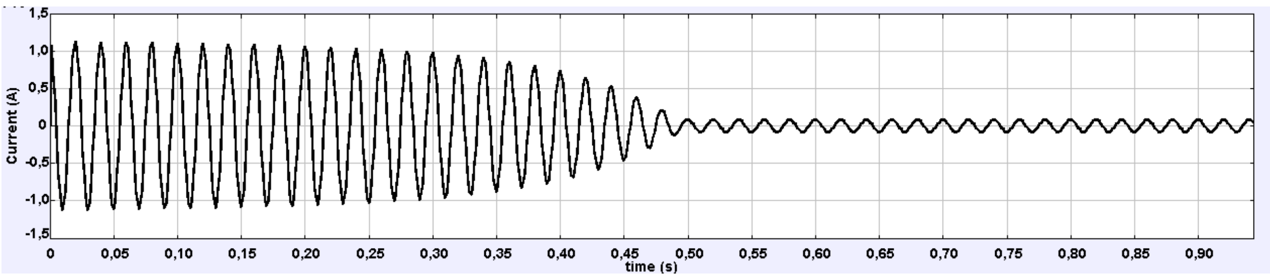
The Three-Phase module has the option of connecting equipment at the power circuit, but the checking module only has a command circuit that the output are substituted by leds that will the work when the output is closed (activaded).

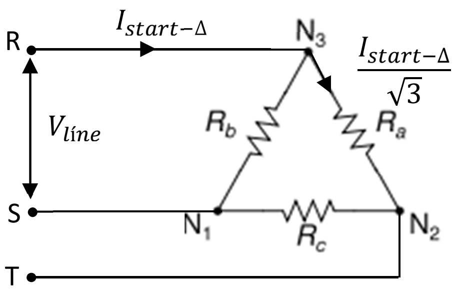
3.3. Electrical engines starting:

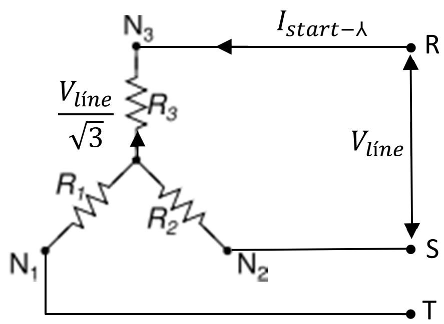
The start-up process is accompanied by a high power consumption, which is justified from the point of view of the equivalent circuit because the load resistance Rc’ is zero at the initial instant, because the value of the slip is the unit, so the engine offers a low impedance, being nearly shorted.



If we take a look how current behaves at an oscilloscope we can observe that, the motor without any load, the current at the start-up it’s higher than the nominal. In order to reduce the star-up current we consider placing at the installation of the engine a star-triangle starter.







$$I_{start-\Delta} = \sqrt{3} \cdot \frac{V_{line}}{R}$$

$$I_{start-\curlywedge} = \frac{\frac{V_{line}}{\sqrt{3}}}{R}$$

Looking for the relation of the Triangle and star start:

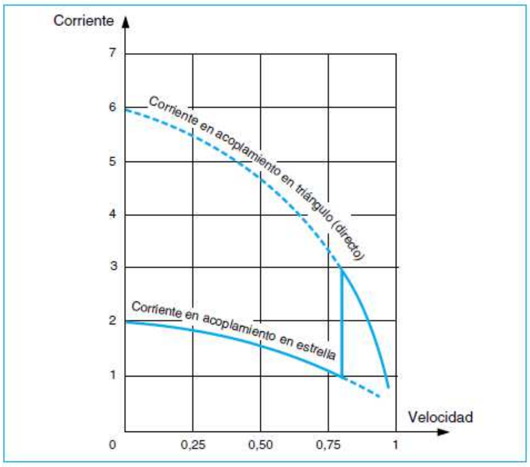
$$\boxed{I_{start-\lambda} = \frac{I_{start-\Delta}}{3}}$$

The machine connected in star consumes less current and gives less torque, with this connection we limit the start-up current.

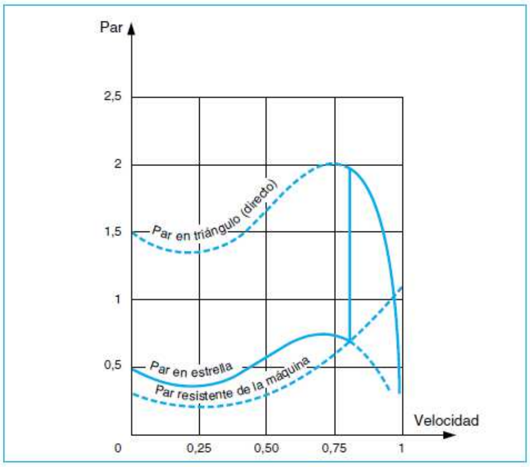
As we have seen in the oscilloscope graph, it takes a little time to see the current reduced, just in the moment that reduces is when we have to change the connection from star to triangle. The discussion is how we do it by using a timer or a PLC.

The star-triangle starter can only be use by engines which the end of every stator finishes at the connector's plate, so that its connection can be modified by contactors. Also we have to take care that the triangle tension matches with the source tension in order to obtain the nominal regime at stationary mode. For example: If we have a three phase source of 380V it is necessary to use a winding motor at 380V in triangle and 660V at star.

This starting mode consists of coupling the winding of star to the source so that voltage is the square root of three times less than the rated motor voltage in star and the peak current is also the squared root of three times less. The power and torque will therefore be three times lower than with the starting triangle directly. Once the torque and load is balanced engine speed is stabilized and then the windings are connected in triangle so that the engine is working at their nominal characteristics. The change from star to triangle is performed by a timer, which causes a delay of 30 to 50 milliseconds between off and off to avoid short circuits.



Curva de corriente/velocidad del arranque estrella-triángulo



Curva de par/velocidad del arranque estrella-triángulo

Due to triangle connection the intensity peak is produced, short in time but important because of the Fcem (Anti electromotive power) of the engine.

Because of current conditions and reduced torque engine, this starting method is only suitable for machines with low load torque or that start idle. Due to the transitional regime of the triangle coupling high power versions are used to mitigate this transition.

Some of these variants are:

• Delay 1-2 seconds over star-triangle: This delay decreases the counter and therefore the peak of current. The inertia of the machine should be such as to avoid excessive deceleration.

• Start in 3 times: Star-triangle + triangle resistance: the time of delay is to be kept at minimum, but in the first instance resistors in series with the triangle connection reduce the input current. After 2 to 3 seconds, these resistances are skipped by a contactor.

• Uncut star-triangle Start: Resistors are placed in series with the winding triangle. Star – triangle change while it is performed without cutting (preventing a short circuit resistance), so that the current flow is not interrupted and no transient phenomena occur.

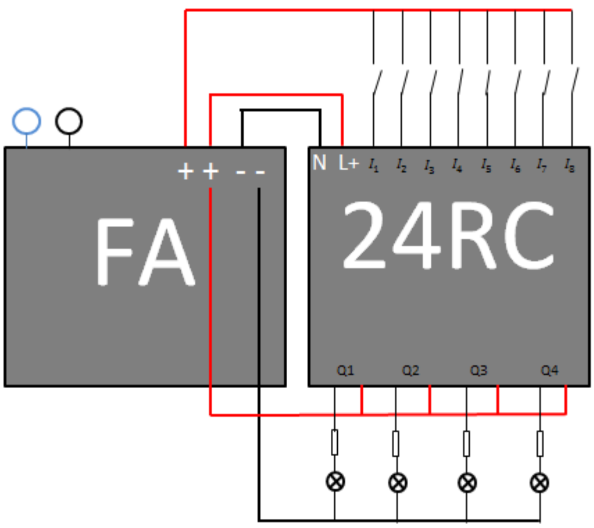
4. MODULE ASSEMBLY AND CONSTRUCTION:

4.1. Electric schemes:

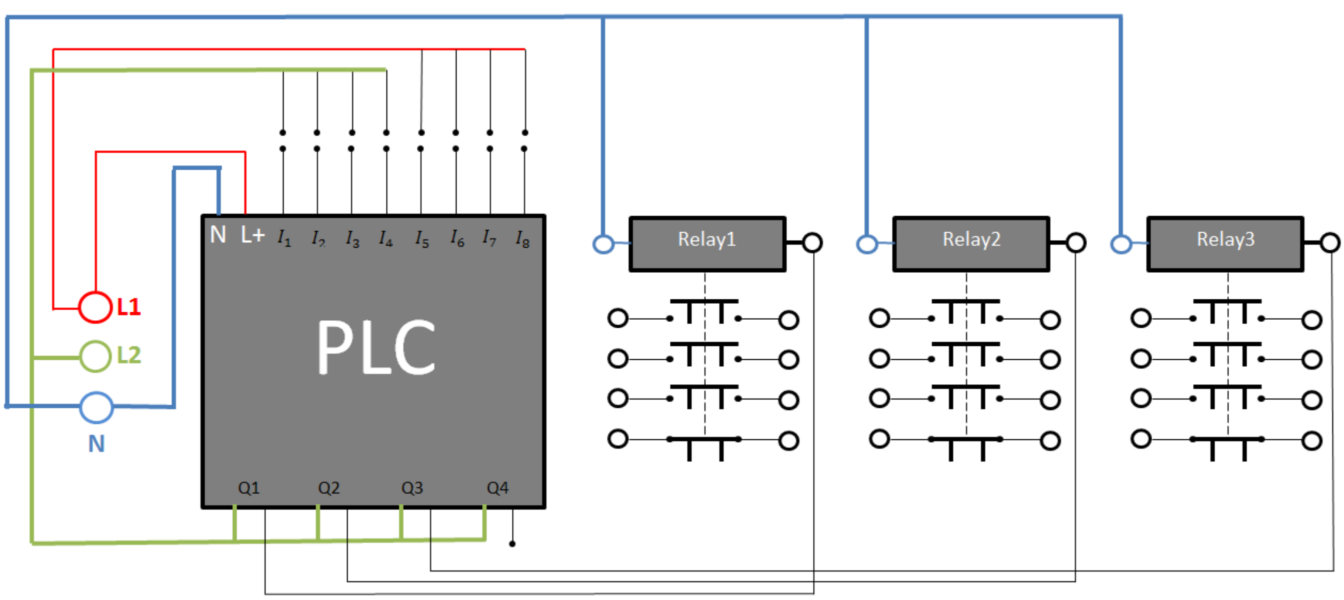
4.1.1. Checking module:

The idea of this module is to substitute the sensors for switches, then when the user downloads the program created in the computer into the PLC. After that by opening or closing the switches that command the inputs we can observe when the leds of the outputs turn on.

The 24RC PLC need a transformer (FA) due to electrical sources are 230V and it works between 12-24V.

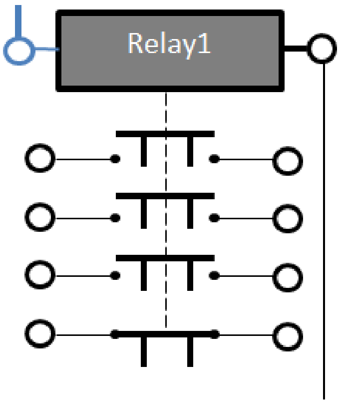


4.1.2. Three-Phase:

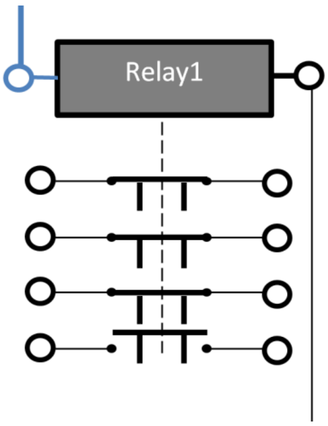


As we can see at the Three-Phase module inputs have two different sources (L1 and L2). L1 sources the last 4 inputs that are opened in order to place whatever the user wants, for example a sensor, a button, a switch…. L2 sources the 4 first inputs which are opened as the other ones for the same reason.

There are 4 outputs. Output Q4 has nothing connected yet. The other ones have a relay designed as we can see at the scheme. Each Relay is a contactor that when the output is activated (has current) the contactor changes its state for close to open and vice versa. It is composed by 3 switches of normally open and 1 switch of normally closed.



Scheme 1: Relay 1 with output Q1 is NOT activated.



Scheme 2: Relay 1 with output Q1 is activated.

In this module we have the interface between both circuits, Power and Command. The connections of the relay (come from the output of the PLC) are from the command circuit but the switches of the relay are from power circuit. The connections of the switches will be the ones that source the equipment.

4.2. Assembly:

After drawing the schemes of each module we had to choose the correspondent components with specifi

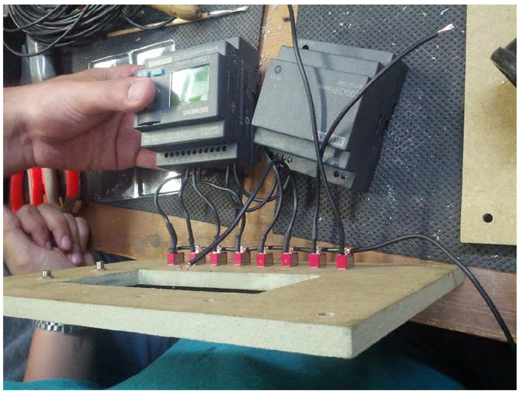
Picture 2. Pre-positioning of the Three-Phase module components.

c characteristics. After obtaining them we had to place them over a wood board to see how we were going to distribute them.

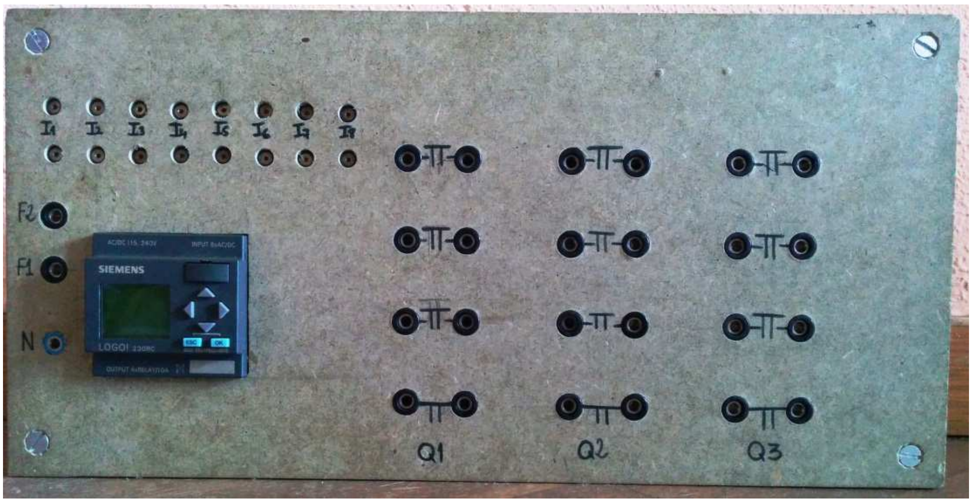
The wood board is easy to drill, non-conducting and cheap, so it was the best option.

Symmetry and position are important so it is necessary to makes marks before drilling the board, an also we have to take into account that not all connectors have the same thickness.

After drilling, place all the connectors and make the connections like in the schemes. The ones that are going into the PLC need to be welded.



And the final modules look like:



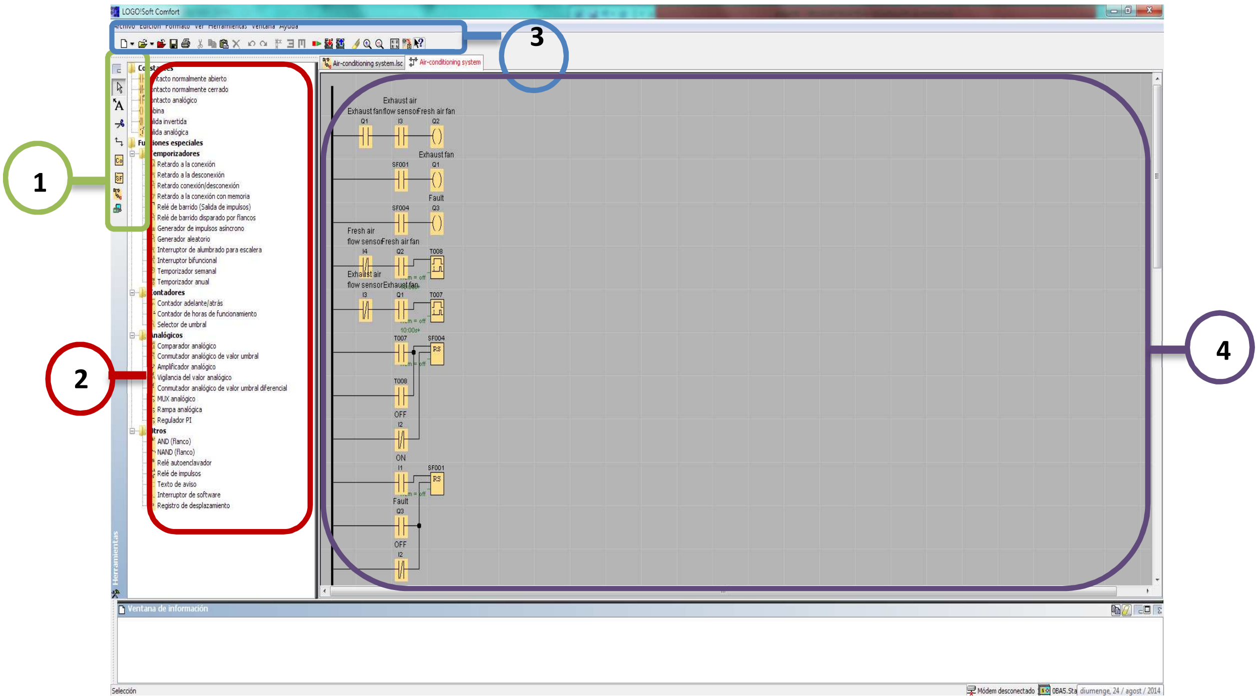
Picture 3: Three-Phase module finished

Picture 4: Checking module finished

5. PLC SETTING AND PROGRAMMING

First of all it is necessary to install de specific program that the company of the PLC offers you, in this case PLC are from Siemens and the program for setting and programing them is <u>LOGO!Soft Confort V6.1</u> it is very important to install it with the CD, not the DEMO version that you can find on internet due to this one does not permit to download the program into PLC.

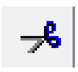
5.1. Logo introduction:



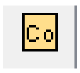
<u>1. Toolbar:</u>

 Selection tool

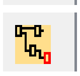
 Text tool

 Joint/Disjoint tool

 Connection tool

 Constants and connectors

 Special functions

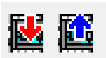
 Simulation

<u>2. Folders:</u> folders with all the connectors, constants etc… available.

3. Standard toolbar: New, open, close, save, print….

And other special buttons:

 Start-Stop simulation.

 Upload and download program from PC to PLC and vice versa.

 KOP – FUP converter and vice versa.

4. **Main screen**. In this screen is created the program.

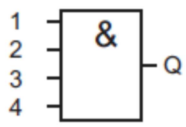
5.2. Logo functions:

Programs can be created by using KOP (ladder scheme) or FUP (Logic gates). KOP is made up for contactors which can work as a switch or a button, timers, delayers etc… and FUP is made of functions like AND, OR, XOR etc…

5.2.1. KOP contactors:

Numbers are inputs and Q's represent outputs.

AND

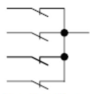


Series circuit make contact

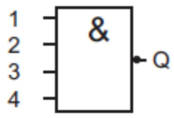
1	2	3	4	Q
0	0	0	0	0
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	0
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0
1	1	0	1	0
1	1	1	0	0
1	1	1	1	1

As we can see at the truth table the function AND has a high output (1) when all the inputs are high (1) or translated into connector's language: All the switches are closed.

NAND



Parallel circuit with break contacts

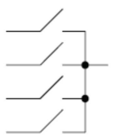


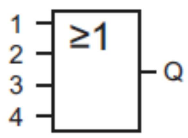
As we can see at the truth table the function NAND has a high output (1) when all the inputs are Low (0) or just one of them. Translated into connector's language: All the switches are connected in parallel.

1	*2*	*3*	*4*	*Q*
0	0	0	0	1
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	0

OR

Circuit diagram of a parallel circuit with several make contacts:





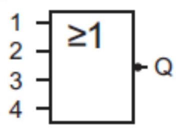
As we can see at the truth table the function OR has a high output (1) when at least one input is high (1). Translated into connector's language: switches connected in parallel.

1	*2*	*3*	*4*	*Q*
0	0	0	0	0
0	0	0	1	1
0	0	1	0	1
0	0	1	1	1
0	1	0	0	1
0	1	0	1	1
0	1	1	0	1
0	1	1	1	1
1	0	0	0	1
1	0	0	1	1
1	0	1	0	1
1	0	1	1	1
1	1	0	0	1
1	1	0	1	1
1	1	1	0	1
1	1	1	1	0

NOR

Circuit diagram of a series circuit with several break contacts:

Symbol in LOGO!:



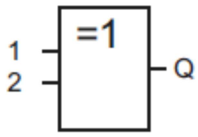
As we can see at the truth table the function OR has a high output (1) when all input are low (0). Translated into connector's language: switches connected in series.

1	*2*	*3*	*4*	*Q*
0	0	0	0	1
0	0	0	1	0
0	0	1	0	0
0	0	1	1	0
0	1	0	0	0
0	1	0	1	0
0	1	1	0	0
0	1	1	1	0
1	0	0	0	0
1	0	0	1	0
1	0	1	0	0
1	0	1	1	0
1	1	0	0	0

1	1	0	1	0
1	1	1	0	0
1	1	1	1	0

XOR

The XOR in a circuit diagram, shown as series circuit with 2 changeover contacts:

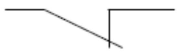


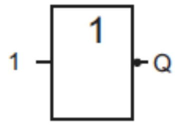
1	*2*	**Q**
0	0	0
1	0	1
0	1	1
1	1	0

As we can see at the truth table the function XOR has a high output (1) when all input are not equivalent.

NOT

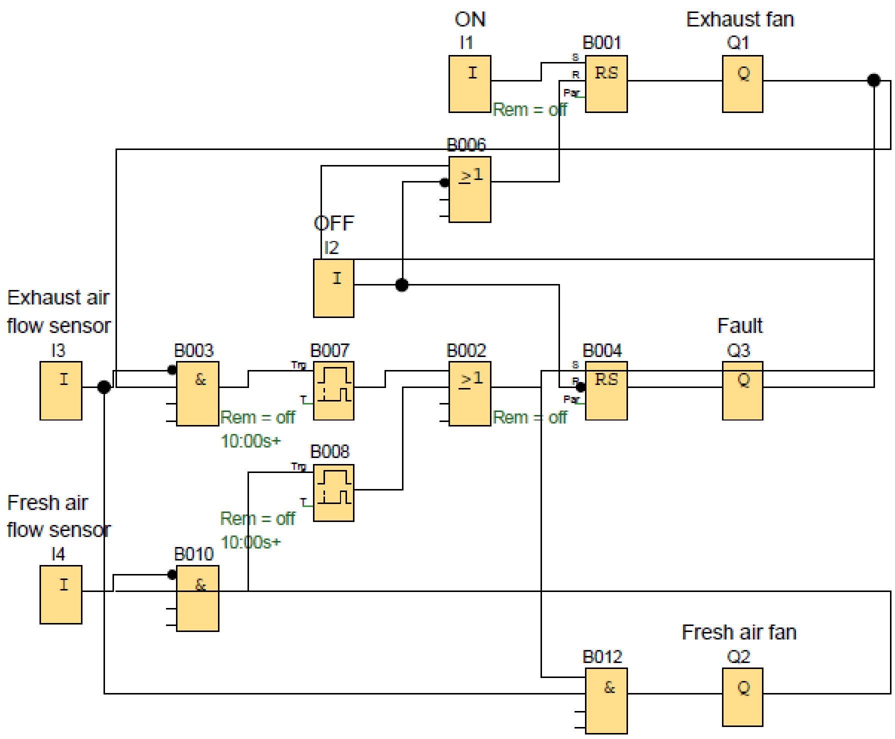
A break contact in the circuit diagram:





1	**Q**
0	1
1	0

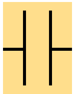
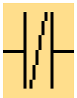
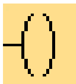
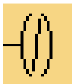
As we can see at the truth table the function NOT inverses the input.

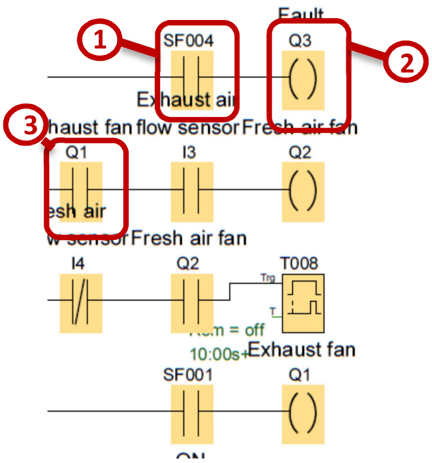


There are more KOP functions but are considered specials like timers, delayers, relays…. Which are included at the Annex.

5.2.2. *FUP functions:*

As explained before FUP functions are based on switches and states Depending on the name given at the program it can be an input or for example an intern function (condition) like when the output Q1 is closed the switch X has to close.

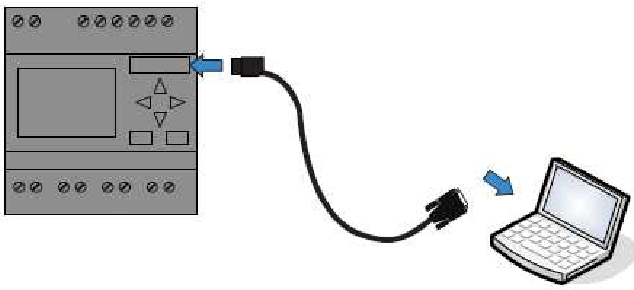
Normally open contact	Normally close contact	
		Represent inputs of the plc
Relay state	**Inverse relay state**	
		Represent outputs of the plc



1	Normally open contact related to a physical switch named SF004.
2	State relay which makes reference to the output of the PLC Q3
3	Normally open contact which changes its state when the output of the PLC Q1 is activated.

5.3. PLC connection with PC:

First of all it is important to have the program of LOGOSoftConfort installed so the computer will recognize the PLC connected. After that is as easy as plug the USB into the computer and the PLC as shown in the picture



6. COMPARISON OF TIMER AND PLC PROGRAM:

Picture 5: Laboratory timer

Picture 6: PLC

It won't be correct if we say that one is better than the other, that is why it is a good idea to explain advantages and disadvantages of both due to depending on the application that they are applied can be completely useful or useless.

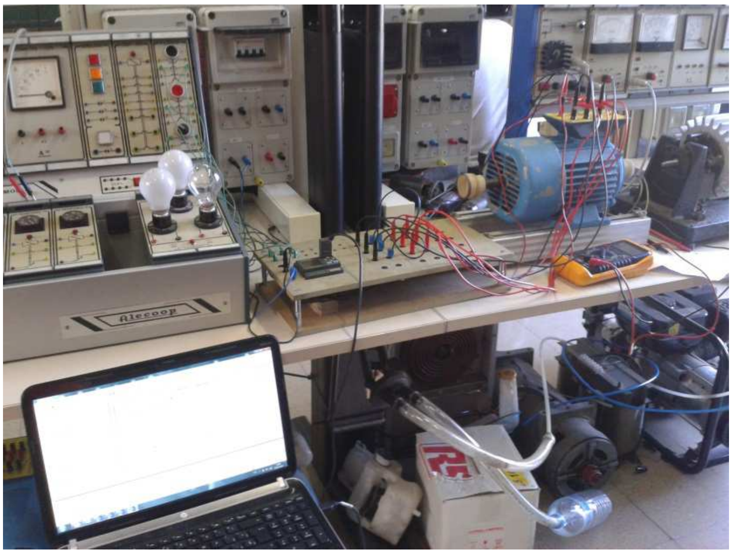
However, PLC is much more complete, due to offers infinity of applications. While the timer is only made of several contactors, that open or close being commanded by a clock, the PLC allows installing any kind of logical automation system but with the physical limitation of the number of inputs and outputs.

The following table summarizes the advantage and disadvantage of both elements:

	TIMER	PLC
Price	Cheap	Expensive (depends on all the functions that it has and trade)
Assembling difficulty	Easy. Most of them have a simple shape.	Medium. Most of them are prepared to go to a DIN rail.
Wiring	Easy. Normally it has one input and	Difficult because it has a lot of

difficulty	one output.	codification inputs and outputs. Also has to be sourced
Precision	Except for the most expensive ones, timers are simple.	It is a CPU so precision it’s one of the most important characteristics.
Versatile	It only measures time and then opens or closes a switch.	Infinite possibilities.
Programing	Does not accept programs	Very intuitive
Constant analyser	Does not analyse.	Very good.

The advantages of the timer are based in its simplicity, on the other hand PLC can be programmed, which opens a lot of opportunities and applications among which is included the timer.



Picture 7: Starting engine with PLC. Laboratory testing.

It is very important to analyse when to use each one, because it is true that a PLC has much more applications but if the duties that this PLC can be successfully substituted by a timer maybe it will be better to use a cheaper, simple device.

When we talk about the engine starting, us always think about a timer because it is what we are used to. A timer begins running while the engine starts and the current is getting lower. After the milliseconds programmed the timer changes the state: Opens the star circuit and immediately closes the triangle circuit.

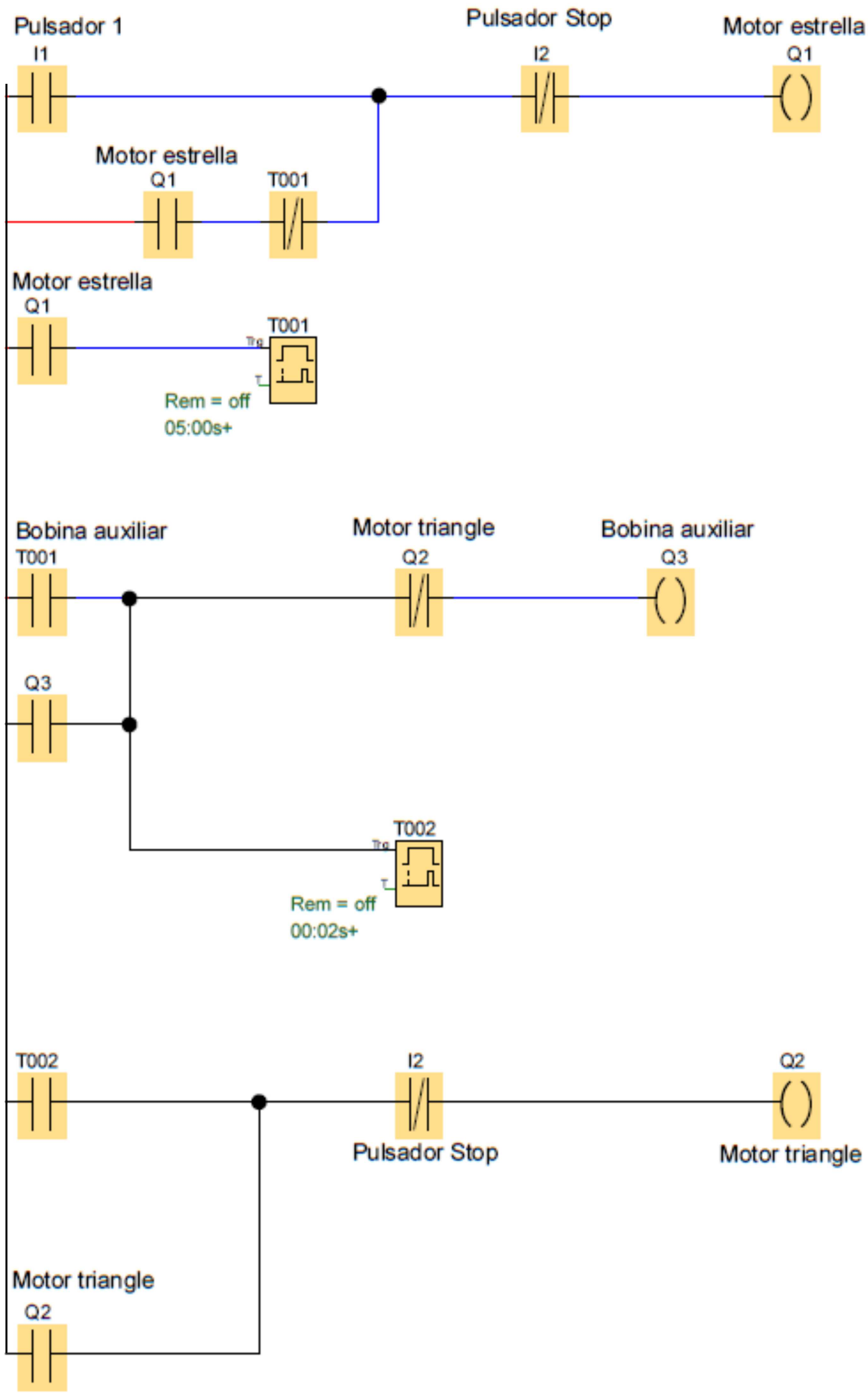
But what could have happened if the current does not get lower and the timer finishes the programmed time and changes the state?

Probably if it does not have any cargo the engine will make a strange noise but if it does it could broke all the expensive equipment related to it.

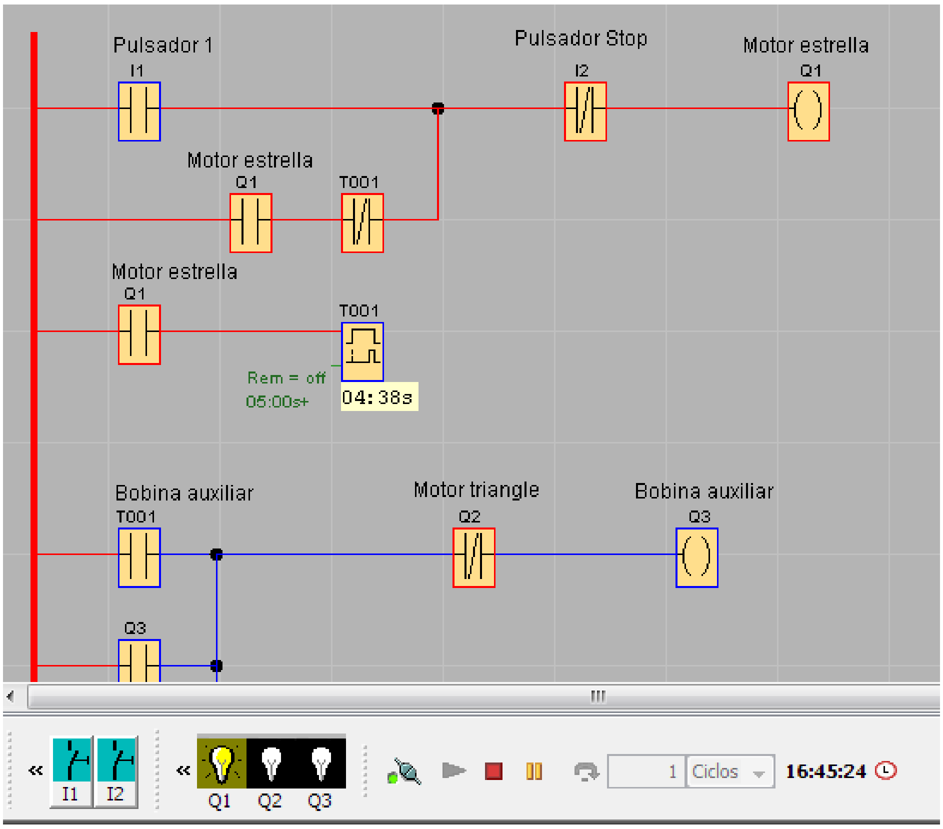
On the other hand the PLC can be programmed for doing the same transition than the timer but taking into account the current of the phase. If this current it is not low enough the PLC will not change the state and also can output a sound or an alarm.

7. TIMER PROGRAM FOR STAR-TRIANGLE STARTING:

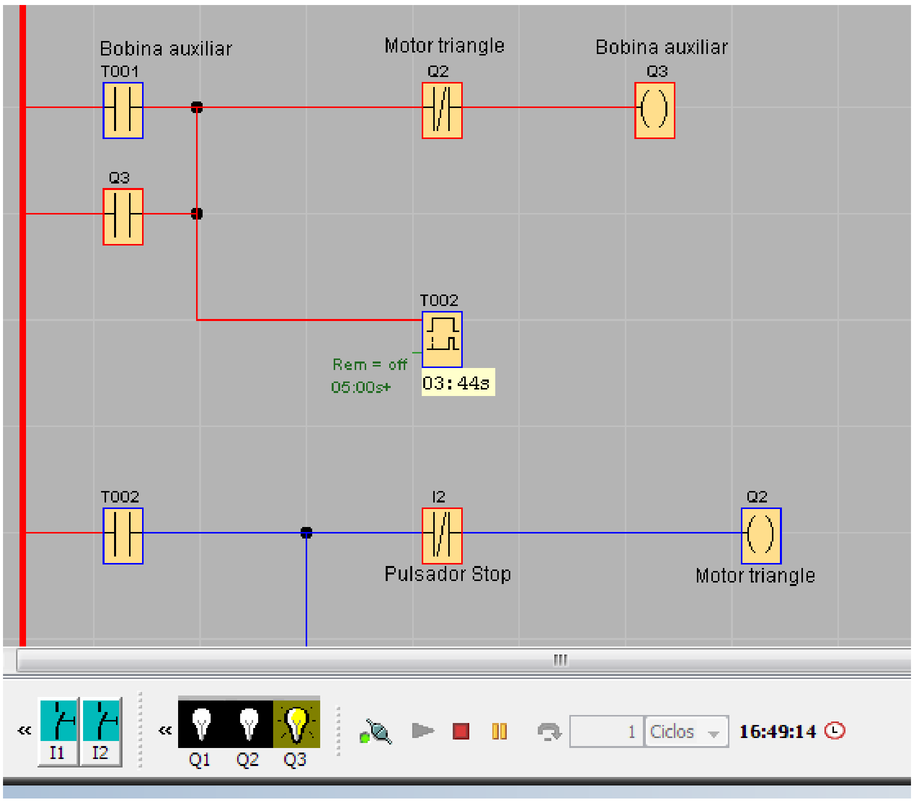
As explained on the chapter 6. PLC's are more complex but more efficient, and versatile. At the beginning of the project my idea was to create a timer program by using simple timers of the electricity facilities but after learning how to use a PLC I though convenient to try it by using the PLC.



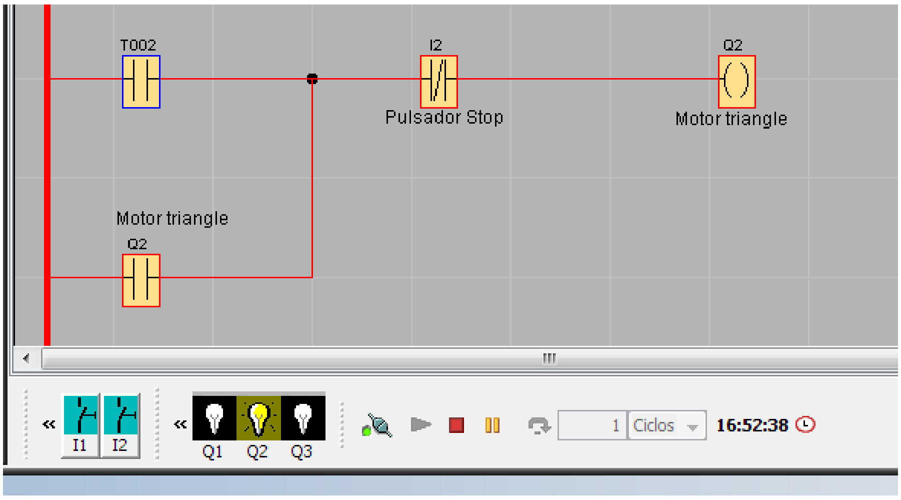
When the button I1 is pushed the engine is started by using star circuit Q3, at the same time a timer starts to countdown. As we can see in red , at the simulation mode of the program, the switches with current, the timer counting and at the bottom the I1 switch and the light represents the relay that is activated at the moment.



When the time is finished the switch related to the timer T001 changes the state to close and deactivates the star circuit and activates another timer T002 (only 2 milliseconds).



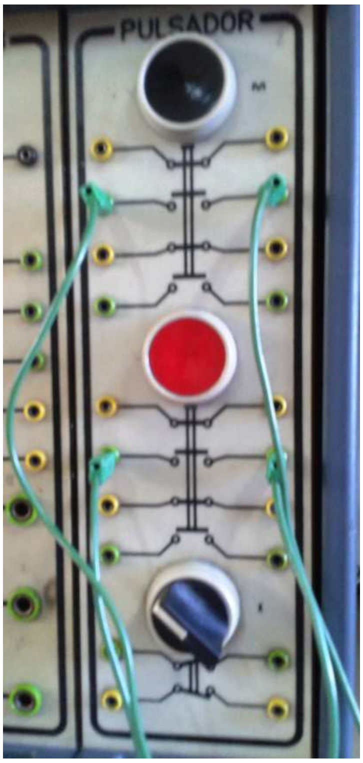
When he timer T002 finishes the countdown activates the relay Q1 which is connected to the triangle circuit.



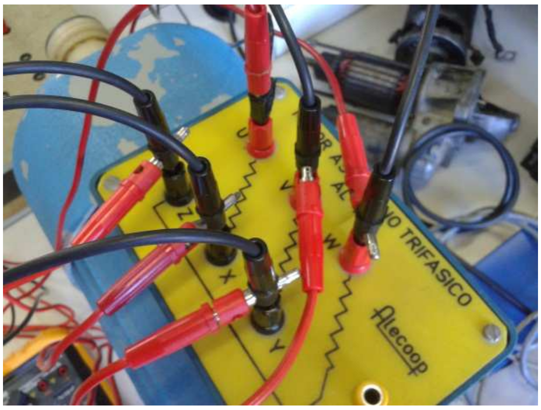
It is not only necessary those switches we have to add a stop button in order to abort the starting.

8. PLC PROGRAM FOR STAR-TRIANGLE STARTING:

It is very important to take care about the names of the contactors, states etc… because this will have to be plashed and connected to the module physically. For example: it the contactor named I1 has to be connected to the input I1.

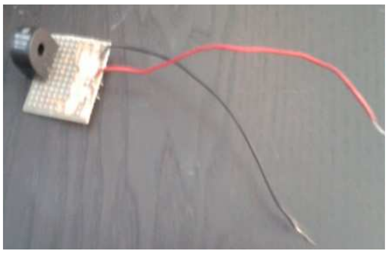


Picture 8: buttons connected to start and stop.



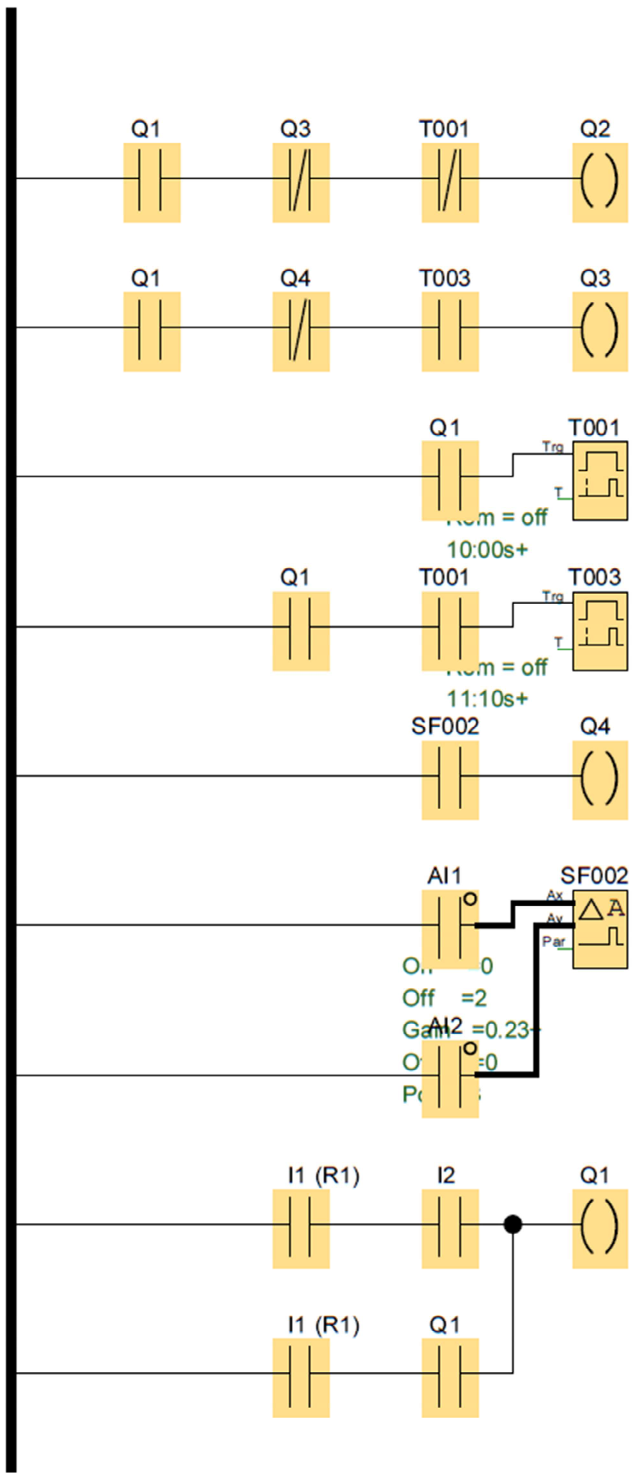
Picture 9:Engine connected to be started by Star-Triangle Program

For this method it will be necessary a transformer that changes the scale of the current of one of the phases due to it will be harmful for the PLC. The scale of the transformer output is between 0-10A.

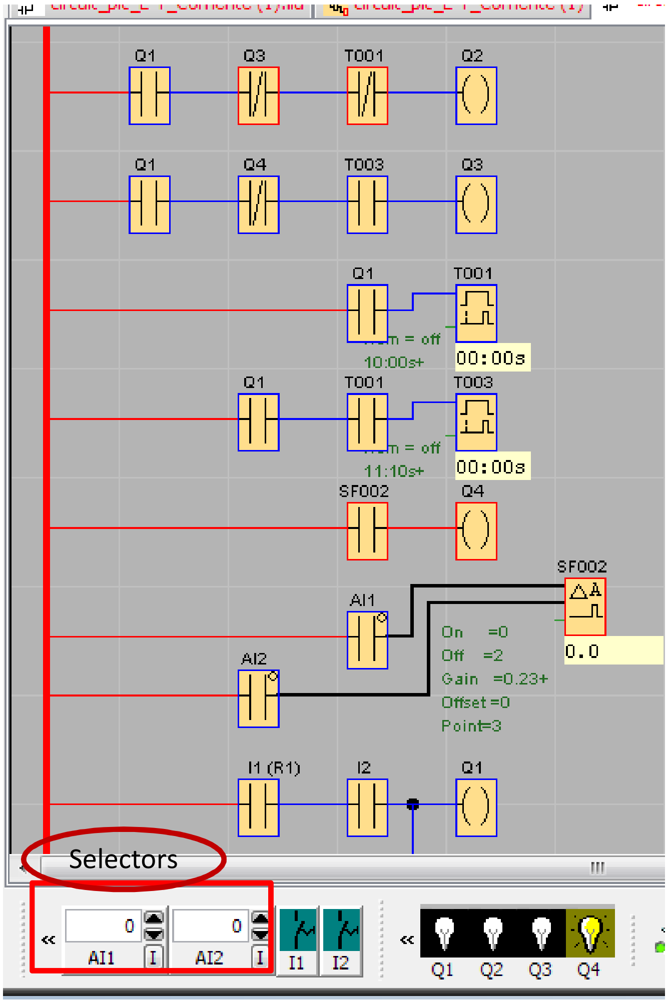


Picture 10: Transformer

equipment.



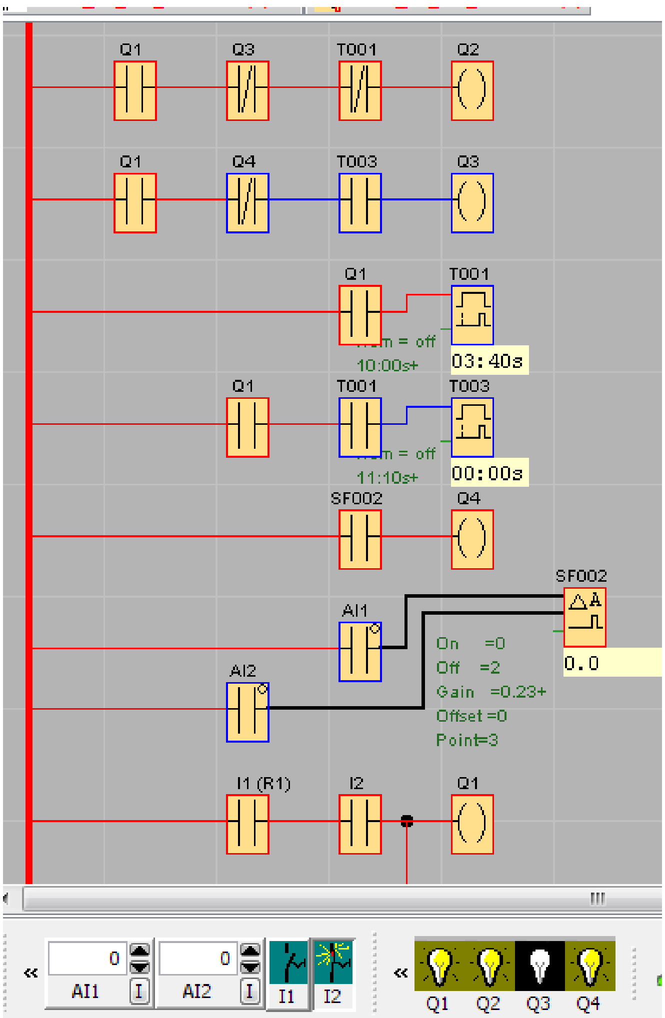
As we can see at the scheme SF002 is a comparer that while the currents of AI1 and AI2 differ more than 2A the program will never connect than triangle due to it could break the equipment.



As we can see in the screenshot Q4 is activated before we press any button. It happens because the difference between AI1 and AI2 is less than 2.

During the simulation we can modify the values of both using the above selectors.

Now we are going to press I2.

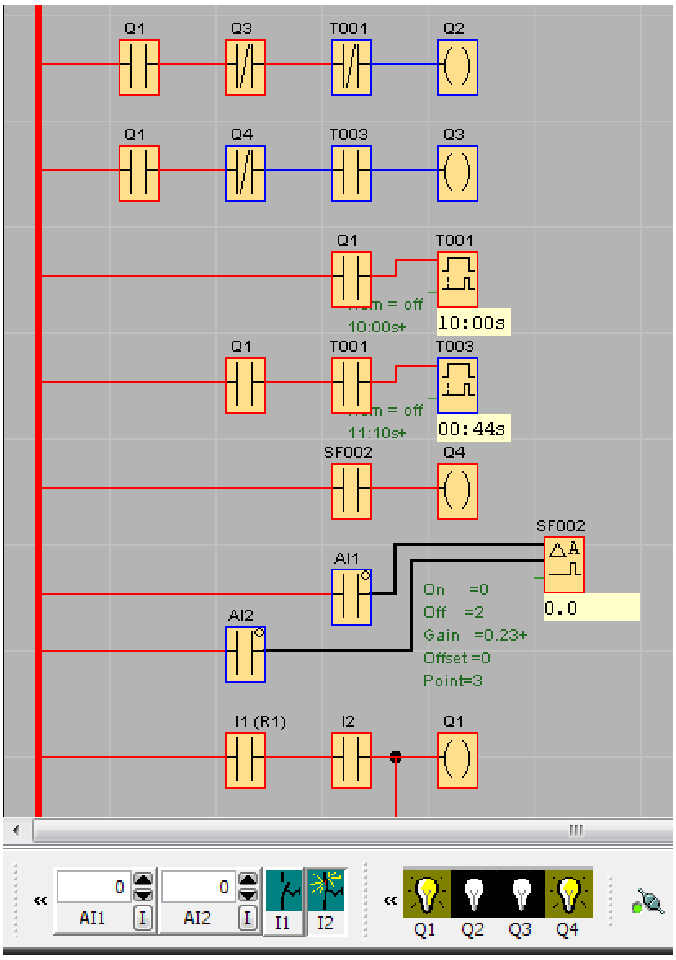


After pressing I2:

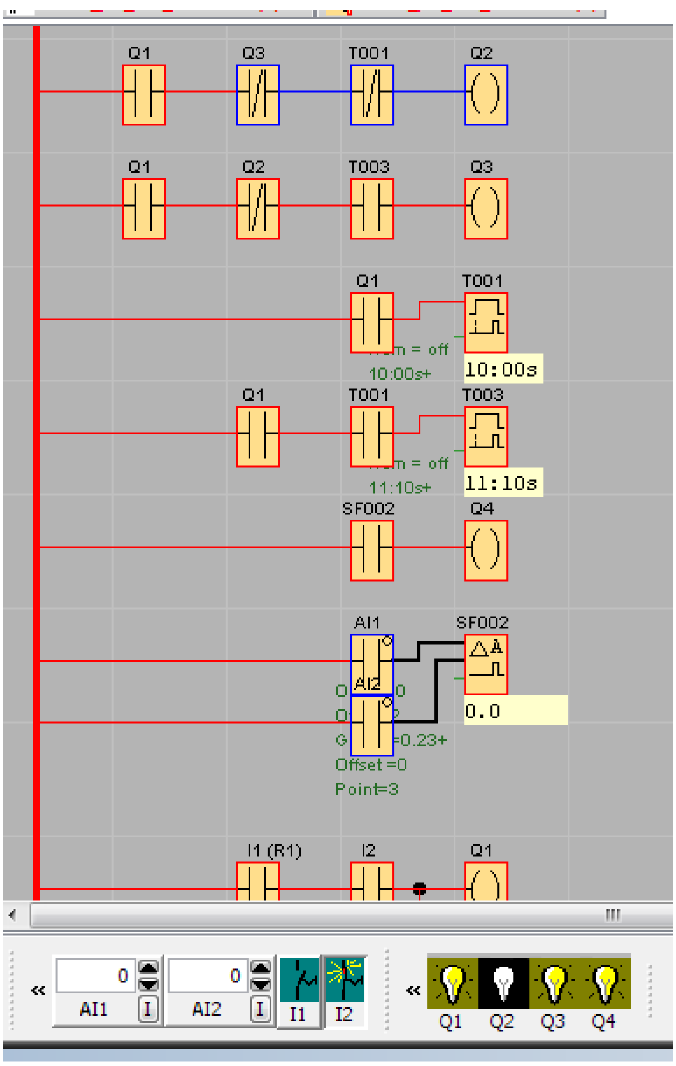
- Output Q1 (star) is activated
- Output Q2 (internal state) is

activated

- T001 starts the countdown.



When T001 finishes the counting it deactivates Q2 and activates the timer T003 which starts de countdown.



After the countdown of the second timer it activates the output Q3 which is related to the triangle circuit.

9. PROPOSED EXERCICES FOR PRACTICE PLC PROGRAMMING.

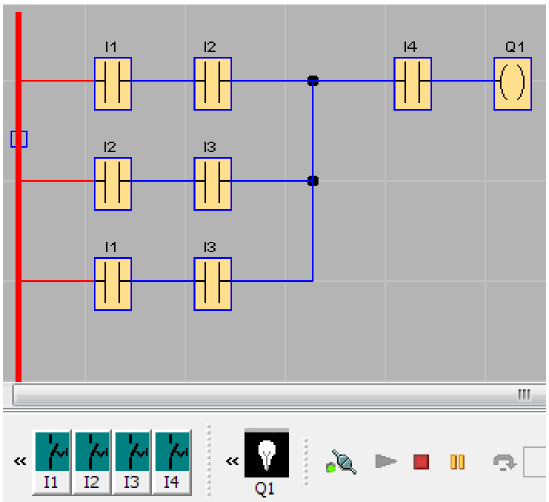
The exercises proposed are to practice with the LOGOSoftComfort program in order to learn who to create a circuit.

9.1. Exercise 1: The alarm system.

The alarm system of a house is made of three movement detectors installed strategically around the house. The alarm is activated when two of the three detectors, at least, have detected a movement. There is a switch hidden in the house to stop the alarm.

- Detector1: 1 when detects a movement, 0 no movement detected.
- Detector2: 1 when detects a movement, 0 no movement detected.
- Detector3: 1 when detects a movement, 0 no movement detected.
- Alarm: 1 Activated, 0 not activated.
- Stop: 1 activated, 0 not activated.

First of all we have to analyse how many inputs and outputs do we have. Detectors are the inputs so we have got 3 inputs, and the alarm is the output (only 1). We can create the program by using KOP or FUP:

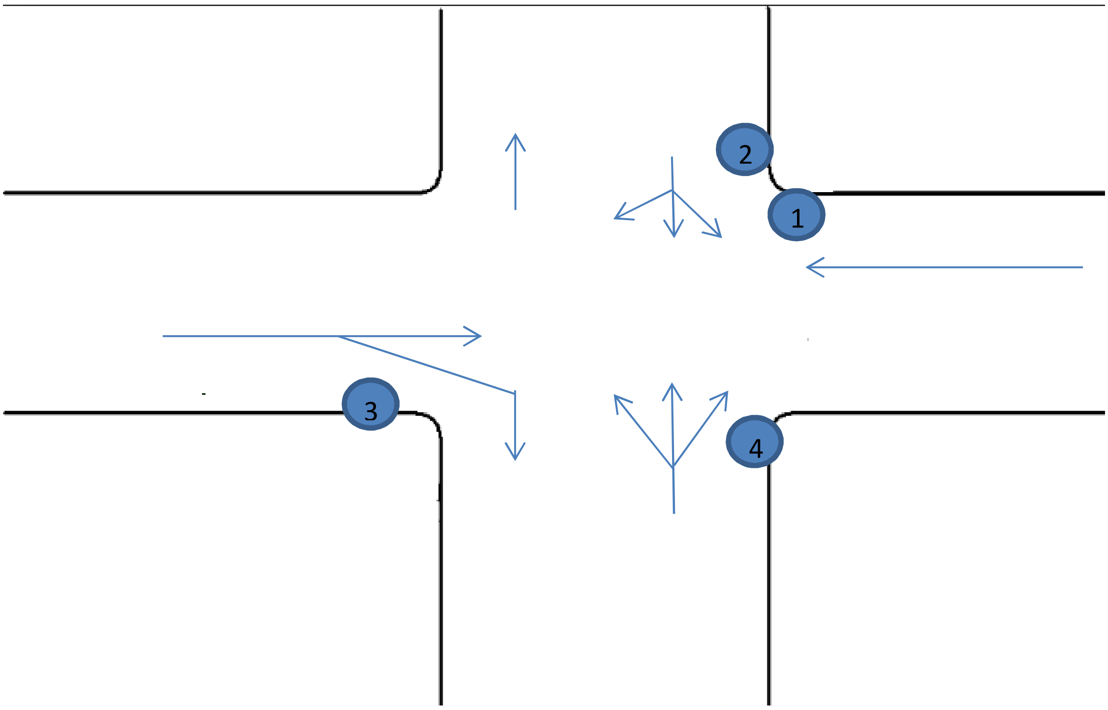


- I1: represents input1, detector1.
- I2: represents input2, detector2.
- I3: represents input3, detectorz3.
- I4: represents input4, STOP.
- Q1: represents output 1, the alarm.

This exercise can be represented by the checking module or the three-phase module.

9.2. Exercise 2: Traffic lighters.

This exercise is prepared for download it at the checking module due to it will use the four outputs.



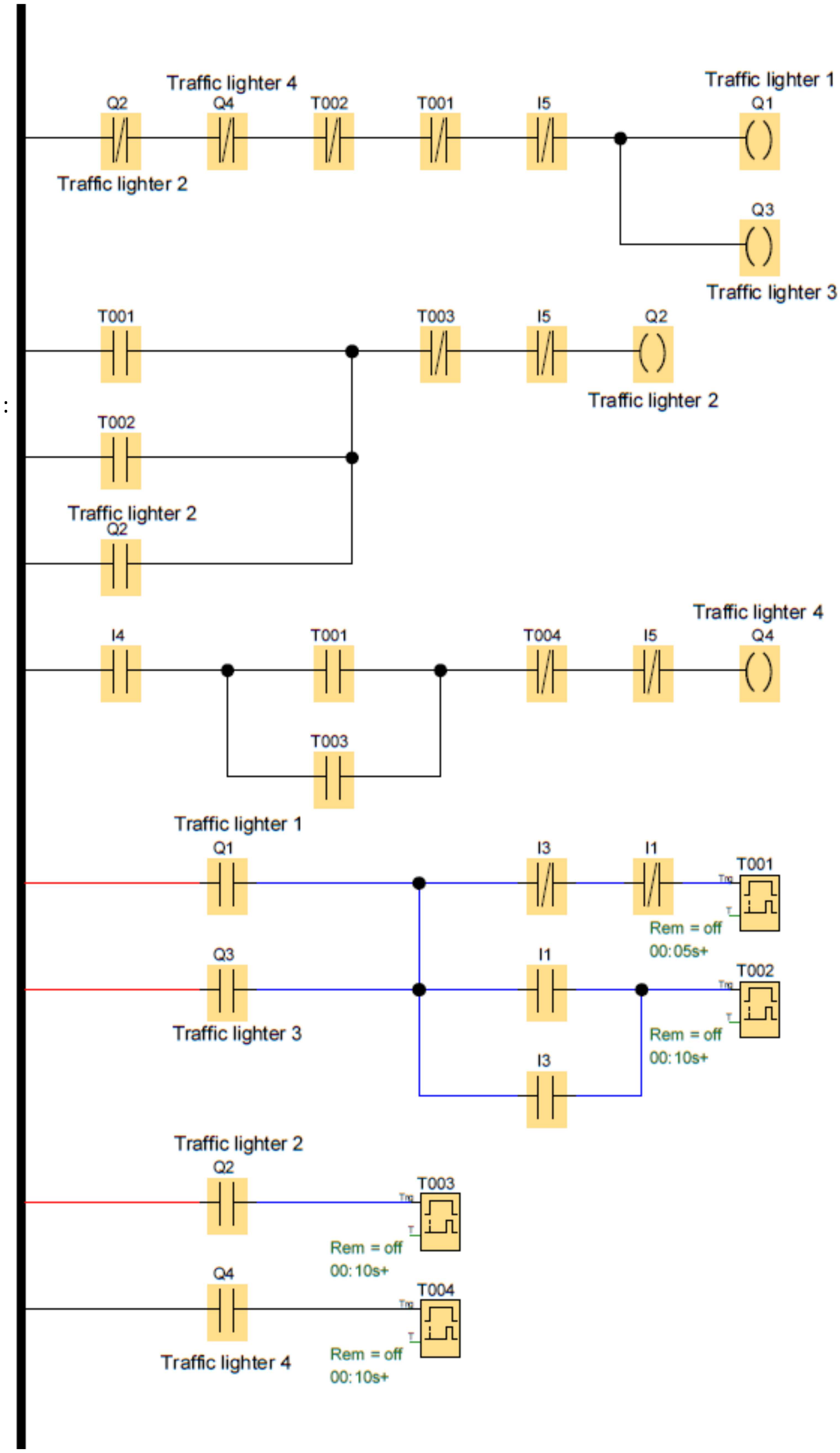
We are going to control 4 traffic lighters, when leds of the module are turned on means that the lighter is green and when they are turned off it means that is red.

- Traffic lighters 1 and 3 have priority (10 seconds working normal state or 15 seconds if the sensor detects cars).
- Traffic lighter 2 has to work 5 seconds after the 1 and 3.
- Traffic lighter 4 works after all three and only if the sensor detects cars (5 seconds)

Between every change of traffic lighter it has to be 1 second of all of them red.

- I1: sensor of cars at 1.
- I2: sensor of cars at 2.
- I3: sensor of cars at 3.
- I4: sensor of cars at 4.
- Q1: Led that represents traffic lighter 1.

- Q2: Led that represents traffic lighter 2.
- Q3: Led that represents traffic lighter 3.
- Q4: Led that represents traffic lighter 4.

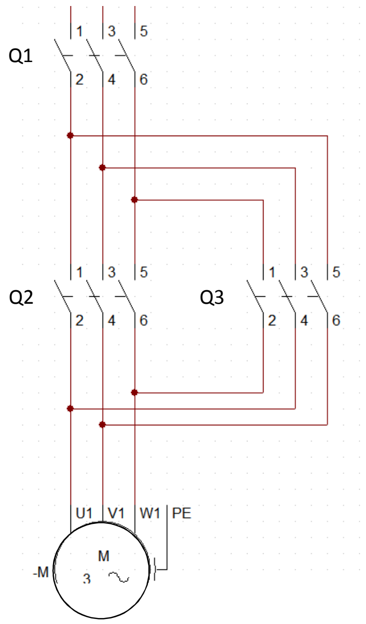


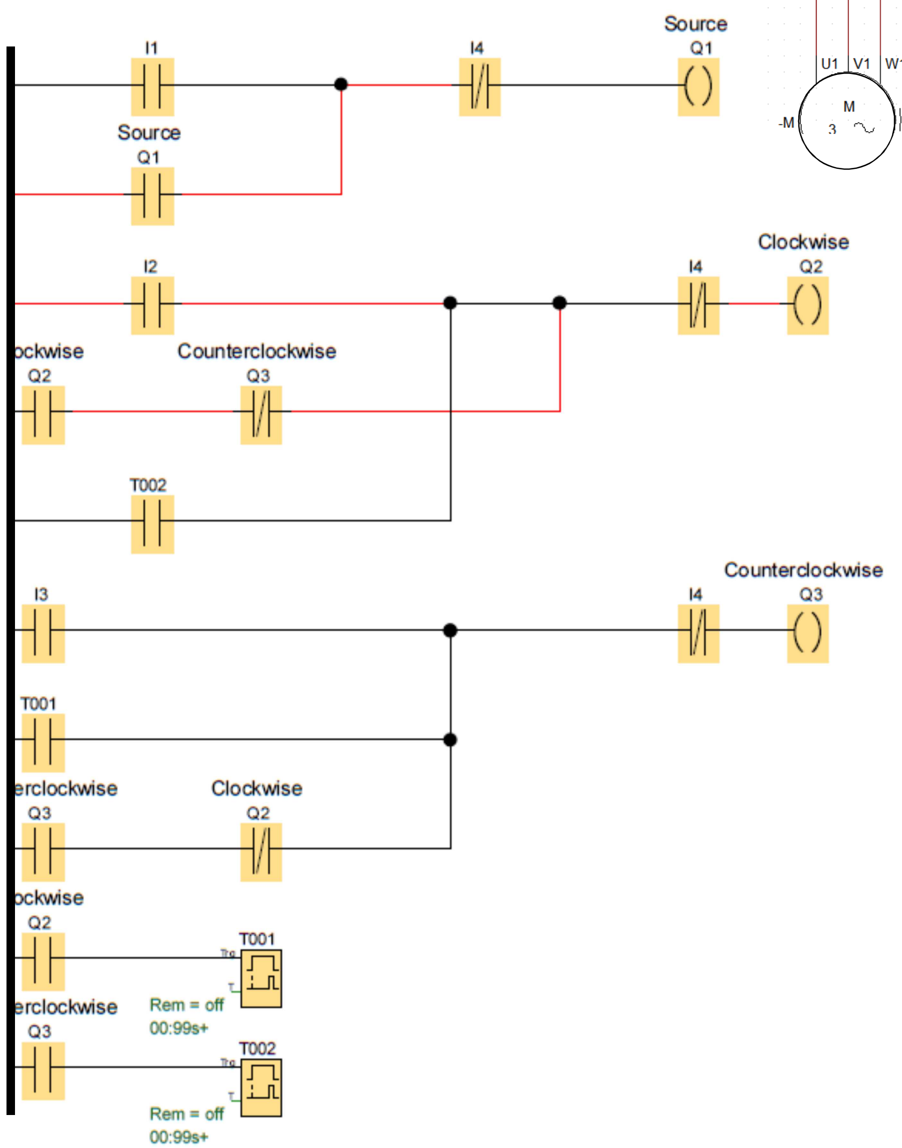
9.3. Reversing motor:

Create a command circuit that reverses the rotational direction of an asynchronous motor. Every 10 seconds it has to reverse or when an order commands a rotational reversing.

Description of the circuit elements:

- Source : output Q1
- Clockwise rotation: Q2
- Counterclockwise rotation: Q3
- Start switch: Input I1
- Clockwise switch: I2
- Counterclockwise switch: I3
- Stop switch: Input I4
- Timer1: T1
- Timer2: T2





10. CONCLUSIONS:

As shown during the project it is based on an assembling part of the modules which involves designing, electricity knowledge in order to create the circuits and skilfulness with tools. The other part is more theoretical due to involve abilities with programing and creating problems to be solves by students.

I think that the problems collection and with the instructions for using the Programming tool will help students creating new circuits or at least practicing and checking them.

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- Tecnología eléctrica Oriol Boix, Luis Sainz, Felipe Córcoles, Francisco J. Suelves.

- Máquinas eléctricas. Fraile Mora, Jesús..